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COMPLETE SPECIFICATION

Improvements relating to Electrical Resistors and Printed Circuits.

We, HAROLD VEZEY STRONG, British Subject, and PAUL EISLER, British Subject, both of 32, Shaftesbury Avenue, London, W.1, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electrical resistors or semi-conductors which consist of one or more layers of a homogeneous or heterogeneous electrical resistance or semi-conducting material or materials mounted upon a stiff or flexible insulating support. Such resistors or semi-conductors may form an integral part of a multi-layer sheet material or stock forming a basis for so-called printed circuits, or they may be used as separate components in the form of labels, strips, transfers or the like for incorporation into electrical circuits, or they may be used for a variety of other purposes as will hereinafter appear.

The production of the resistors or semi-conducting components in printed circuits has so far been generally more complicated than the production of separate components, but the latter can for the purpose of this invention be regarded as merely a special case of the printed circuit technique. The invention will therefore be described more particularly in relation to printed circuits, but it is to be understood that the principles, methods and products herein described in relation to printed circuits can readily be adapted or modified as necessary for the production of separate circuit components.

For convenience, in the following description and claims the terms " resistor " and " resistance " will be used, except where the context otherwise requires, to mean not only a component in which a particular fixed or variable ohmic value is the primary requirement, but also a component which exploits the characteristics of the classes of substances known as semi-conductors. Thus, in the present specification, a " resistor " is essentially a component consisting of one or more layers of a substance which is a non-insulator and which exhibits an appreciable ohmic resistance, and which extends between highly conductive electrodes or terminals, whether this component is used purely for the reason of its ohmic value, or because its ohmic value is a function of another variable, or for some special effect. Examples of such components which would not ordinarily be classed as " resistors " but which are regarded as coming within the scope of this term for the purposes of the present specification are:—

Strain gauges, pressure gauges, microphones and gramophone pick-ups, where a resistive or semi-conducting layer is subjected to a mechanical force, either steady or vibratory, which affects the value of its ohmic resistance.

Temperature indicating devices such as thermistors, which consist of a semi-conducting layer (e.g. uranium oxide) the ohmic resistance of which varies greatly with changes of temperature.

Light-sensitive elements such as layers of the sulphides, selenides or tellurides of zinc, cadmium or lead, which are photo-conductors.

Rectifying devices such as layers of selenium or cuprous oxide whose ohmic resistance varies according to the direction of the applied voltage, or crystal rectifiers (e.g. layers of silicon carbide, silicon or germanium situated between a large contact and a very small contact).

Devices based on the thermo-electric effect.

Devices based on the Hall effect.

Transistors and the like. In the filamentary transistor a thin germanium film extends between a relatively large base and a collector electrode, and a small emitter electrode is arranged between the base and the collector electrode.

One object of the invention is to provide

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a multi-layer stock in sheet or strip form for the manufacture of such resistors or printed circuits containing them.

Another object is to provide convenient electrical resistors for the purposes set forth, while a further object is to provide convenient terminal arrangements for the resistors.

Further objects will appear from the following description.

According to one aspect of the invention a multi-layer stock in sheet or strip form for the manufacture of electrical resistors (as defined above) or printed circuits containing them comprises an insulating support, at least one layer of electrical resistance material adhering to the support, and a layer of a highly conductive material of negligible square area resistance adhering to the outer surface of the resistance material and in intimate electrical contact therewith.

The conductive layer is such that it can form conductors for an electric circuit, and also has sufficient strength to serve as terminals to which electric connections can be made if required.

The invention should therefore not be confused with a prior proposal for the manufacture of a composite resistor comprising a thin film of copper over a graphite coating on a non-conducting base, since in that case the copper film forms part of the resistor itself and must therefore be so thin as to have a significant ohmic resistance. Moreover, a thin film of this kind would be too fragile to serve effectively as a terminal.

Before the stock can act as a resistor an area of the highly conductive layer must be removed, since if an electric potential is applied between two points on a single area of the highly conductive material the current will flow almost entirely through this material so that the underlying resistance layer or layers will be ineffective. But if the two points are on two separate areas of the highly conductive material and an exposed area of the resistance material extends between them, the current will have to flow through the resistance material.

The ohmic value of the resistance will depend upon the specific resistance of the material itself and its thickness, and will also depend upon the shape (i.e. the length and breadth) of the exposed area. It may also depend to some extent on the direction of the resistor axis, or upon a deformation of the support, as will be explained hereinafter.

Separate highly conductive areas at two ends of an area of the resistance layer act as terminals by which the current is led into and out of the resistance layer. Since the highly conductive layer is in intimate electrical contact with the resistance layer the current can readily pass from the terminals into the resistance layer, and vice versa. Also, since the resistance layer is in one plane there is no undesirable " step " such as occurs in conventional printed circuit technique where resistors are formed by painting on or otherwise applying resistance coatings to a support which already bears a conductive pattern. In such a case the resistance coating must overlap the conductive areas to which it is to be connected, and a " step " occurs where the overlap begins.

In certain cases there may be two or more layers of resistance material between the insulating support and the highly conductive layer, these resistance layers having different chemical and/or physical properties. By selectively removing the outer layer or layers of resistance material, resistors having different resistance values per square area can be made. The requirement that these resistance layers must be capable of selective removal is the reason for their having different chemical and/or physical properties, since the layers can then be selectively removed by treatment with different agents.

The multi-layer sheet material consisting of an insulating support, one or more layers of resistance material, and an outer layer of highly conductive material forms the stock or raw material from which printed circuits or separate components can be made. Essentially, the method of converting the stock into the desired product comprises the selective removal of unwanted layers, to leave areas having the required electrical properties, namely insulating areas (all layers above the support removed), resistance areas (the conductive layer removed, and in certain cases also one or more resistance layers from above the particular resistance layer required), and conductive areas (no layers removed).

Thus according to another aspect of the invention a method of making an electric resistor or a printed circuit containing a resistor from a stock as aforesaid comprises selectively removing certain areas of a layer or layers by treatment with an agent or agents capable of removing the said layer or layers, while protecting from the action of the agent or agents those areas of the said layer or layers that are to be retained. This protection may be afforded either by the presence of an overlying area which is unaffected by the agent or agents, or by the prior application of a protective coating.

The outer highly conductive layer of the stock preferably consists of a pre-formed metal foil such as copper foil, tinned copper foil, aluminium foil, zinc foil or silver foil, and any convenient foil thickness may be used, for instance 0.002". The metal of the foil should preferably be soft. Other kinds of highly conductive layer may be used as will be described hereinafter. The metal of these layers should preferably be capable of

being soldered so that other conductors or components can be connected to them easily.

For the insulating base or support almost any insulating film or sheet material can be used. However, since it is usually desirable for the stock to be flexible and mechanically strong it is preferred to use a flexible insulating sheet material, for instance insulating impregnated paper or fabric. Obviously the insulating material must be such that it is unaffected by the various agents employed for selectively removing the superimposed resistance and conducting layers.

Where capacitors are made from the same stock the insulating support should be very thin and must be made of a material having uniform dielectric properties to make it usable as a capacitor dielectric of known square area permittivity.

Many circuits require a stock where the insulating support and one or more resistance layers are sandwiched between two highly conductive layers, and so the invention embraces not only stock in which there are layers on only one side of the insulating support, but also stock in which there is on the side of the insulating support opposite to that which carries the said resistance and highly conductive layers, a further highly conductive layer either alone or associated with at least one further resistance layer.

In certain applications of the invention it may be desirable to contact the resistance layer on some areas from the side adjacent to the insulating support. For many such applications the insulating support may consist of a soluble plastic film or varnish, or it may be a perforated sheet with a soluble plastic film filling the perforations. Alternatively the material of the support may be such that it is easily pierced or split mechanically. Over the area where contact with the inner surface of the resistance layer is desired, the insulating support is dissolved away or pierced, and the exposed inner surface of the resistance layer is metallised or otherwise provided with an electrical contact. For instance, one type of transistor which has the emitter and collector contacts on one side of a germanium layer and the base on the other side can be made in this way.

The material for the resistance layer or layers may take several forms. It may be, for instance, a thin continuous layer of a metal having a specific resistance which is considerably different from that of the outer highly conductive layer. For instance if the outer layer is copper, lead or a nickel-chrome alloy could be used for a resistance layer.

In order to produce stock capable of providing metallic resistors which are stable in value over a wide range of temperatures the following technique may be employed.

In the first place a bimetallic foil is prepared consisting of a layer of a highly conductive metal, and a comparatively much thinner layer of a metal having a high specific resistance and a small temperature coefficient of resistance. The bimetallic foil may be made in a number of ways. For instance, possible methods include cladding by a rolling process, electro-deposition, chemical deposition, vacuum deposition, and deposition from the colloidal state followed by suitable heat treatment.

The highly conductive layer of the bimetallic foil will comprise the outer conductive layer of the stock, and must be capable of being etched away or otherwise removed by an agent which does not attack the thin layer of resistance metal. If desired the selective removal of the outer conductive layer can be assisted by providing a thin parting film of conducting material between the two metal layers, this film being removable by an agent which does not harm the thin layer of resistance metal. The parting film may be a very thin metal film or a non-metallic film such as a carbon-resin film.

As regards the constitution of the metal of the thin resistance layer, an alloy of manganese (over 80%) and copper heat treated to over 600°C. would be very suitable. This alloy has been reported to have a resistivity of 500 to 1600 microhms per centimetre cube, and a very small temperature coefficient. Other suitable alloys are, for example, certain copper-manganese-nickel alloys; copper-nickel alloys; nickel-silvers (i.e. alloys of copper, nickel and zinc); copper-silicon; copper-nickel-chromium; chromium-nickel; and chromium-nickel-iron. Some alloys of noble metals are also suitable, for example silver-palladium.

Factors which govern the choice of the alloy are, for instance, the requirement of differential solubility of the alloy and the metal of the foil and the ease of forming a layer of the alloy on the foil. The foil base for the alloy layer permits of a continuous and readily controllable layer-forming operation, the choice of surface from very smooth to deeply grained, and the use of high temperatures during or after the formation of the layer on the foil.

Another important class of materials suitable for forming the resistance layer or layers consists of carbon powder or graphite powder or colloidal graphite in a binder. Such layers can be produced by coating the foil or the insulating backing, for instance by roller coating, the coating preferably being thinned by being carried in solution or as an emulsion. After coating the carrier is driven off, for instance by evaporation. Alternatively, self-supporting films from about a half-thousandth of an inch up to a few thousandths of an inch thick can be made when certain binders are employed. These films

can then be bonded to the insulating support or to the metal foil with the aid of heat and pressure. The bonding of the resistance layer to the insulating carrier is preferably effected or assisted by the use of an insulating cement, while the bonding of the resistance layer to the metal foil can be effected or assisted by the use of a conductive cement.

A type of carbon and graphite of a dense single-phase structure and known by the name "Delanium" (a Registered Trade Mark of Powell Duffryn Carbon Products Limited) should be suitable for coating on to the metal foil and heat treatment *in situ*. A coating of this sort should have a large number of carbon-to-carbon linkages, and should provide a more crystalline layer or film than is obtainable with other forms of carbon, requiring a minimum amount of binder or even enabling a binder to be dispensed with altogether. The term "coating" is intended to cover any suitable method of depositing or providing a layer of "Delanium" carbon or graphite on the metal foil.

The resistance layer need not necessarily extend completely over the metal foil or insulating support. Thus it may be of reticular form, i.e. in the form of a pattern consisting of a network of straight or curved lines which may be of any desired width or thickness. The lines of network may be produced, for instance, by printing a negative of a half-tone screen on to the foil with a resistance ink.

The binder for the particles of the resistance material must be compatible with the particles, and may be a synthetic or natural glue, rubber or resin. In the latter case a resin mixture is preferably used, which is plasticised to render it less brittle and uniformly adhesive, unless the resin or resins themselves have this quality. The binder should be insoluble in water and non-absorbent when in its finished state. It must be unaffected by the agent employed for removing the unwanted parts of the highly conductive outer layer. Hence it is preferably stable to acids or electrolytes used in etching processes, particularly iron perchloride or copper sulphate baths. Preferably the binder should be of a flexible nature. A further characteristic which the binder must have is that it must be capable of removal from the insulating support by an agent which does not affect that support whether this agent be heat or a solvent or a chemical reagent or mechanical forces such as those acting in abrasive treatments.

Where there are two or more layers of resistance material the binders of each resistance material must be capable of selective dissolution so that an agent which is used to remove one layer of resistance material will not affect the other layer or layers. The binder of an inner resistance layer, that is a layer which is not immediately adjacent to the outer conductive layer, need not necessarily be resistant to the agent used for removing the outer conductive layer, since this resistance layer will normally be protected by the outer resistance layer or layers during the metal removing process.

The following are examples of suitable binders.

Bichromated fish glue rendered water and acid-proof by heating to about 350° C.

Resins which are soluble in alcohols but are insoluble in aromatic hydrocarbons, such as shellac or vinyl acetate.

Synthetic rubbers such as neoprene, or resins such as the styrenes, which are soluble in aromatic hydrocarbons but are insoluble in alcohol.

Silicone rubbers and non-thermosetting adhesive resins such as polyvinyl chloride based adhesive mixtures, which are soluble in acetone and have relatively high temperature stability.

Silicone resins made flexible, thermosetting resins, alkyds and bases of heat resisting enamels which when completely set become insoluble. These substances are useful for layers which can be removed or patterned by abrasive treatment.

Fusible binders such as modified waxes and polythene. These last are applicable only for very low wattage loading of the square area.

Although the above list is far from being exhaustive it can be seen that numerous substances can be selected as binders which adequately comply with the requirements outlined above. A number of combinations of binders are possible which will permit selective dissolution of the resistance layers formed with these binders.

Among the principles which guide the selection of a suitable resistance material some are quite obvious, such as the necessity of using a flexible material when the insulating support is itself flexible and is required to be bent or folded.

Another principle guiding the selection is the required specific value of the resistance per unit of area required for the particular resistance layer. Layers consisting of powdered carbon in a binder, or layers consisting of "semi-conductive" metal compounds, are generally more suitable for high ohmic resistances than are layers consisting of metal alone. When a very high wattage loading per unit of area is required a silicone-bound carbon layer carried on a silicone impregnated glass fibre cloth support is recommended, since a very much higher wattage loading is permissible than with a shellac-bound or like layer on an impregnated paper support. Consequently the resistors can be made smaller with the former

materials than with the latter.

Preferably the binder is selected so that it can itself serve to bond the resistance layer to the metal foil or to the insulating support, whereby the use of additional cements is avoided.

Where the stock is to be used for making printed circuits where noise level is of importance, it is preferred to use a resistance layer consisting of a metal or a metal compound, or, if a carbon layer is used, to ensure that there is proper contact between the carbon particles.

Another possible class of resistance layers consists of thermosetting, thermoplastic and elastomeric variants of conductive materials known as "Markite" conductive plastics, which can be supplied with a conductivity ranging from approximately that of mercury to that of high conductivity rubber, or boron, or even lower. (See pages 96 to 99 inclusive of "Electronics" for October 1949, published by McGraw Hill Publishing Co. Inc., New York, U.S.A.) Thin films or coatings of two selectively soluble "Markite" plastics, or of a "Markite" plastic and another resistance layer, can be employed for the purpose of the invention.

The above examples of resistance layers are mainly for those resistors which exploit the ohmic value of the layer. Substances of the semi-conducting class may be used as the resistance layer or layers for the production of resistors used for other purposes, such as rectifying, amplifying, or exhibiting sensitivity to changes in temperature or in the quality or intensity of incident light. Intrinsic semi-conductors (silicon, germanium, or lead sulphide) can be used, as well as impurity semi-conductors such as various metallic oxides, sulphides, selenides or tellurides, and elements such as selenium and tellurium. These semi-conductors can be coated on to a metal foil, which as indicated above in connection with metallic resistance layers affords high controllability and ease of heat treatment, as well as other advantages such as freedom from chemical contamination and exclusion of atmospheric influences.

Having given an indication of some types of resistance materials, foils and insulating backings which may be used in the stock, various methods of manufacturing printed circuits incorporating resistors will now be described by way of example with reference to the accompanying drawings in which:—

Figures 1 to 7 illustrate the various stages of one method of manufacturing a three layer circuit;

Figure 8 illustrates a stage in an alternative method of manufacturing a three layer circuit;

Figures 9 to 15 illustrate various stages in a further method of manufacturing a three layer circuit;

Figures 16 to 24 illustrate various stages in one method of manufacturing a four layer circuit:

Figures 25 to 33 illustrate various stages in another method of manufacturing a four layer circuit;

Figure 34 illustrates the structure of a five layer stock, and

Figure 35 illustrates the structure of a modification of a four layer circuit during its manufacture.

The drawings are highly diagrammatic; for instance, the thickness of the layers in relation to their areas is very much greater than would be the case in practice, and their relative thicknesses may differ substantially from those adopted in practice, which will vary widely depending upon requirements.

The method of manufacture illustrated by Figures 1 to 7 produces a three layer circuit in which the area A is to comprise a single layer of insulating material only, the area B is to comprise a double layer consisting of an insulating layer overlaid with a layer of resistance material, and the area C is to comprise three layers, namely an insulating layer overlaid with a layer of resistance material which is in turn overlaid with a layer of highly conducting material.

The stock from which the circuit is to be manufactured is made up as follows.

A sheet of copper foil F is roller coated with a mixture of colloidal graphite (or other carbon particles) in water and bichromated fish glue. The coating is dried and is then heated to 350° C. so that the carbon-containing layer is burned into the copper foil and becomes insoluble and unattacked by water or etching agents such as iron perchloride. The layer adheres firmly to the foil and forms a coating R which, while conductive, has a considerably higher specific resistance than the foil. The coated foil is very flexible.

The coated side of the foil is now cemented to an insulating support S, for instance an insulating impregnated paper, using an insulating cement which is removable by means of a solvent. Thus a synthetic rubber which is soluble in acetone would form a suitable cement. The resulting stock is a three layer sheet as shown in Figure 1 in which the resistance layer R is sandwiched between the foil F and the insulating support S.

The resistance values of the layer R can be calibrated, after the usual ageing and other conditioning treatments of the stock, by cutting out test pieces at various selected points in the length and width of the stock, removing the foil from certain areas in the manner hereinafter described, and thereafter measuring the resistance values of the exposed areas of the resistance layer R. It

is important that the test samples should be subjected to the same treament steps as the stock will have to undergo in practice. If the resistance values of the test pieces are found to be of the required magnitude and sufficiently uniform, the stock is marked with its resistance value per square area, and this value can form the basis of the design of the pattern of a printed circuit for which the stock may be used.

For printed circuit work the stock may be treated so as to provide areas as aforesaid having three different kinds of electrical properties, namely:

(A) areas from which both the metal foil F and the resistance layer R have been removed, leaving the insulating base S without any conductive coating;

(B) areas from which only the metal foil F is removed, leaving a resistance layer R on the insulating base; and

(C) areas from which nothing is removed and comprising metal foil overlying the resistance layer and the insulating base.

In printed circuits the areas A comprise non-conducting areas, the areas B comprise resistors the value of which depends upon the length and breadth thereof, while the areas C comprise conducting areas. The conducting areas C may be used, for instance, to form terminals, inductances, inter-connections and shieldings, and in some cases may comprise the electrodes of capacitors.

In order to convert the stock shown in Figure 1 into the printed circuit shown in Figure 7, in which the various layers in the areas A, B and C are as set out above, a pattern is first printed in two different protective inks on to the metal foil, as shown in Figure 2. One ink D is printed over the foil in the areas C, while the other ink E is printed over the foil in the areas B. In the areas A the foil is left bare. The printing process used may be analogous to the normal "two colour" printing processes, but the inks need only be capable of visual distinction for reasons of control. Both the inks D and E must be acid-resisting, but they must be capable of being dissolved selectively in different solvents. Thus ink D may be soluble in aromatic hydrocarbons and insoluble in aliphatic hydrocarbons, while ink C is soluble in aliphatic hydrocarbons but not in aromatic hydrocarbons, or vice versa. The ink D must be alkali-resistant, but the ink E can be alkali-soluble.

The next stage is to submit the printed sheet to a metal-dissolving process, for instance a chemical etching in an iron perchloride bath, until all the metal foil layer F has been removed from the exposed area A as shown in Figure 3. Next the sheet is placed in an alkali bath which removes the exposed resistance layer R from the Area A as shown in Figur 4. This removal is helped if the cement used to bond the layer R to the support S is not resistant to alkalis.

In the next stage the sheet is treated with a solvent for the removal of the ink E from the area B as shown in Figure 5, for instance by immersion in a bath or by spraying. If the ink E is alkali-soluble the two stages illustrated by Figures 4 and 5 will occur simultaneously. On the other hand, if the ink E is not alkali-soluble the two stages could still be conducted simultaneously by treating the sheet with a mixture of an alkali and the solvent for the ink E, or with a mixed spray of both liquids.

In the next stage the sheet is again subjected to etching, which removes the metal foil F from the area B as shown in Figure 6.

Finally, after washing with water, the sheet is treated with a solvent for the ink D. With the removal of this ink the required circuit is left as shown in Figure 7, in which the area A comprises the insulating support S, the area B comprises the resistance layer R overlying the insulating support S, and the area C comprises the metal foil F overlying the resistance layer R which in turn overlies the insulating support S.

It will be appreciated that the treatment baths will only affect the exposed areas of materials which are soluble in or attacked by the baths, the other areas of these materials being protected by superimposed layers or inks which are not affected by the particular bath concerned.

In an alternative method which in most respects is similar to the method described with reference to Figures 1 to 7 the ink E is printed over the areas B and C, while the ink D is printed over the ink E in the areas C, as shown in Figure 8. This method affords greater protection to the conductive pattern during the etch treatment.

It is not essential to provide sharply defined edges between the areas in all cases. For instance, instead of a straight line border between the metal foil F and the exposed resistance layer R a serrated edge may be provided with many thin tongues of metal extending into the resistance area. In this way a smoother gradation between the highly conducting area C and the area B of relatively high resistance may be achieved. It is also possible, and in some cases to be preferred, to thin down the foil layer C where it adjoins the resistance area B by using a similar technique in the printing and etching process as is used for obtaining different tone values in making a gravure cylinder. This technique consists in making the ink D gradually less resisting to the acid as it approaches the resistance area B. This can be done by using a continuous tone printing technique such as gravure and relying on the variation of ink thickness to give the required variation in acid resistance, or by

using a third ink layer on the area in question and relying on the same effect, or by printing a kind of half-tone pattern of the ink D over the ink E (Figure 8) so finely that when the sheet is immersed in the solvent for the ink E those areas of the ink E which are underneath the half-tone pattern of the ink D are not completely removed during the time of the treatment. These areas then protect similar areas of the metal foil during the subsequent etching treatment. The degree of dissolution is a function of the density of the half-tone printing. If the printing is done photographically the ordinary photogravure method is applicable. In this case the varying degree light hardening of the gelatine determines the permeability of the resist to the iron perchloride and thus the degree of etching of the copper foil.

A variation of the printing and etching method described in relation to Figures 1 to 7 and Figure 8 is illustrated in Figures 9 to 15. In this method it is unnecessary to use inks having different solvent characteristics, and moreover it enables the resistance coating of the area A to be removed more quickly, for instance by assisting its dissolution mechanically by swabbing or by abrasion, such as gentle scratching. With a somewhat more drastic abrasive treatment it is possible to remove layers which are insoluble, such as carbon films with binders of fully cured thermosetting resins or vulcanized rubbers. Abrasion may be used alone, or it may be accompanied by swelling treatment or blast action. The metal foil pattern itself can be used as the resist to protect from abrasive action the portions of the underlying layers which are not to be removed.

In this method the three layer stock employed (Figure 9) is the same as that shown in Figure 1. In the first stage the areas B and C are both over-printed with a single layer of ink E, as shown in Figure 10. Next, as shown in Figure 11, the printed sheet is etched, thus removing the exposed metal foil from the area A. If the agent for removing the resistance layer R will also remove the ink E the sheet is next subjected to treatment with this agent, whereby the exposed resistance layer R from the area A and the ink layer E from the areas B and C are simultaneously removed, as shown in Figure 12. This removal can be effected by a dry or wet abrasion process, or by a solvent or swelling agent for the resistance layer and for the ink film, assisted by swabbing if required, since the material beneath the ink layer comprises only metal foil and the material beneath the exposed resistance layer comprises only the insulating support, which are mechanically robust. Alternatively, if the agents for removing the ink E and the resistance layer R are not the same, the state of Figure 12 can either be reached in two stages from the stage of Figure 11 or else, if the two agents are mutually compatible, they may be mixed in a single bath, or applied in some other manner in a single application.

Next the sheet is coated over the areas A and C with an ink, lacquer, or other protective substance G, for instance by printing, painting or spraying, as shown in Figure 13. During this stage the area B is masked, for instance by a stencil. Consequently the foil layer F remains exposed in the area B. The sheet is now subjected to a second etching treatment whereby the exposed metal foil is removed from the area B, as shown in Figure 14. Finally the coating G is dissolved from the areas A and C to leave the desired product as shown in Figure 15. As the support S is unattacked by the etch bath, the ink coating G in the area A may be omitted if desired.

With any of the methods so far described the exposed surface of the resulting sheet may be coated with a non-conducting lacquer, except for those parts of the area C where electric connections are to be made. or the final dissolution of the ink film covering areas C may be effected only on these connection areas. It may sometimes be preferable for the exposed areas of carbon-filled resistance layers also to be left bare, since it has been found that a lacquer coating may on occasion produce unpredictable disturbances in the electric characteristics of such layers. A variation of the method just described may be used in cases where the resistance layer needs a protective coating. This variation will be described later.

The products of the methods described above are printed circuits having conducting areas, non-conducting areas, and integral resistance areas. The latter can have any desired value which may be obtained by suitably designing the shape and by using a square area of the single resistance layer R of suitable square area resistance value. Since it is known from the tests referred to above either that this value is uniform over the whole sheet, or, if it varies, the extent and nature of this variation, the actual value of the resistor will conform to the designed value to a high degree of accuracy. Conversely, the actual value can be accurately predicted from the design data.

In some cases the range of resistance values obtainable by a single resistance layer will not be sufficient, and two or more layers of different resistance materials having different resistance values per square area will be needed. The stock in such cases may consist of an insulating support and a sheet of metal foil sandwiching two (or in some cases three or even more) layers of resistance material which are in intimate contact with

each other.

If two layers are found to be sufficient for the circuits in question, as shown in Figure 16, the two resistance layers R^1 and R^2 must not only have the required resistance values per unit of area, but must be capable of being selectively removed, the layer R^2 being unaffected by the agent used for removing the layer R^1. It is not necessary that there is full reciprocity; the layer R^1 need not be unaffected by the agent used for the removing the layer R^2, since it can be protected during the removal of the unwanted parts of the layer R^2 by the metal foil and or a protective coating or imprint.

The stock shown in Figure 16 may be made up as follows. First of all a sheet of copper foil F is electro plated with an extremely thin lead film which is then converted into lead sulphide by treatment with sodium sulphide to form a resistance layer R^1. This layer is then roller coated with a carbon-filled neoprene solution constituting the other resistance layer R^2. Finally the double coated foil is secured to an insulating support S, for instance impregnated paper, by a suitable cement. The resulting stock is then tested to ascertain the resistance values of the layers R^1 and R^2 on the lines indicated in connection with Figures 1 to 7.

Instead of coating the layer R^2 completely over the layer R^1 it may be applied in reticular form as a series of crossing lines by cross ruling as shown in Figure 17. The network of lines shows a very fine appearance with frequent crossings of the lines. It is so designed that the lines are closer together in one direction H than in the other direction J so that in a given square area the resistance value in the direction H will be greater than the resistance value in the direction J. This enables two different resistance values for the layer R^2 to be obtained from an area of resistance material of a given shape, depending upon the direction in which the terminals are arranged. The resistance values in the different directions are determined empirically and are added to the design data for the stock.

The network of lines shown in Figure 17 is made by straight line ruling, but other arrangements may be employed. Thus, for instance, a ruling pen may be oscillated or be moved in circles, so that wavy, cyclic or other curved lines are drawn. Alternatively the pattern may be printed with any design of intersecting lines. The ruling of groups of straight parallel lines at an angle to each other will usually have to be done in two steps, whereas other methods such as printing or ruling with rotating or oscillating pens can be accomplished in only one step.

Apart from the directional values of the resistance of the layer R^2, the stock shown in Figure 16 is capable of providing in printed circuits areas having four different characteristics, as follows:—

(A) Layers F, R^1 and R^2 removed, leaving only the insulating support S.

(B^1) Foil layer F only removed, leaving the resistance layer R^1 superimposed on the resistance layer R^2 of substantially greater specific resistance, which in turn lies on the insulating support S.

(B^2) The foil layer F and the upper resistance layer R^1 removed leaving only the resistance layer R^2 of relatively high specific resistance upon the insulating support S.

(C) No layers removed, so that the area is highly conducting.

In order to convert the stock of Figure 16 into the required product of Figure 24, a pattern covering the areas C and B^2 is printed on the foil using an ink D. A second printing is then carried out which superimposes a layer of ink E over the layer D in the area C, and also over the foil in the area B^1. The printed stock is shown in Figure 18. The inks must be capable of selective dissolution: for instance the ink D may be a bituminous ink and the ink E a shellac ink.

Next, the printed material of Figure 18 is etched either chemically, for instance in nitric acid, or electrolytically by being made the anode in a suitable copper and lead sulphide dissolving bath, whereby the copper layer F and the lead sulphide layer R^1 are removed from the area A as shown in Figure 19. Next the sheet is treated in a benzene bath, for instance, which removes the exposed carbon-filled neoprene layer R^2 from the area A and also dissolves the exposed layer of ink D from the area B^2 as shown in Figure 20. The ink E covering areas B^1 and C is not attacked by benzene.

Next the sheet is etched as before, with the result that the metal layer F and the lead sulphide layer R^1 are removed from the area B^2 as shown in Figure 21.

In the next step the sheet is treated with methylated spirit in order to remove the shellac ink E from the areas B^1 and C, but it will be observed that the metal foil F in the area C still remains covered by the layer of ink D which is not soluble in methylated spirit. The sheet now has the form shown in Figure 22.

The next step is the removal of the copper foil F from the area B^1 without removing either the layer of lead sulphide R^1 beneath it or the exposed resistance layer R^2 in the area B^2. This can be done by etching the copper anodically in an electrolyte which does not enable lead sulphide to go into solution. This electrolite may consist of a copper sulphate solution kept neutral by the addition of calcium carbonate for instance. This method is rather slow, and a quicker method of removing the copper is first to treat the sheet in a cyanide bath until only

a thin film of copper is left and then to transfer the sheet to a bath of the aforesaid electrolyte for removing this thin film of copper. Thorough washing is required after the removal of the copper foil F from the area B^1. The product now has the form shown in Figure 23.

In the next step the whole sheet is sprayed with a layer of nitro-cellulose lacquer N except for the electrical connection points on the area C, which can be masked by a stencil. Finally the sheet is treated with benzene which removes the ink D from those parts of area C which were shielded by the stencil, the nitro-cellulose lacquer N protecting the layer R^2 in the area B^2 from the action of the benzene.

The resulting product is shown in Figure 24. If desired the nitro-cellulose lacquer N can be removed but this is not essential.

Another method of preparing a four layer printed circuit is shown in Figures 25 to 33. First of all a stock somewhat similar to that of Figure 16 is prepared, except that in this case the foil is fairly thick and the layer R^2 consists of, say, carbon-filled shellac, while the layer R^1 consists of a series of intersecting lines ruled with, say, a carbon-filled alkyd resin ink. The coated foil is heat treated so that the shellac film still remains alcohol-soluble while the alkyd film is rendered insoluble in any organic solvent. This stock has the form shown in Figure 25. Next a coating of ink D, for instance a bituminous ink, which is resistant to the etching chemicals or to the anodic bath for the removal of copper is printed on the areas B^1, B^2 and C as shown in Figure 26. Next the sheet is subjected to chemical or electrolytic etching to remove the copper layer F from the area A as shown in Figure 27.

Next, as shown in Figure 28, the sheet is subjected to a wet abrasion process such as scrubbing with a scouring powder which removes the ink layer D from the areas B^1, B^2 and C, and also removes both the resistance layers R^1 and R^2 from the area A.

In the next stage the sheet is coated with a shellac lacquer E, except for the areas B^1 and B^2 where the metal foil is left exposed as shown in Figure 29. This exposed foil layer is then removed by chemical or electrolytic etching as shown in Figure 30.

Next a layer of nitro-cellulose lacquer N is applied to the areas A and B^1 and also to those parts of the area C on which the foil is not required to be exposed. The sheet now has the form shown in Figure 31. Next the sheet is treated with methylated spirit which dissolves the shellac lacquer E wherever it is not protected by the nitro-cellulose lacquer, N. The methylated spirit also dissolves the layer R^1 from the area B^2 as shown in Figure 32. If desired the areas B^2 may be finally coated with protective lacquer N by stencilling, giving a product as shown in Figure 33.

A stock with three resistance layers R^1, R^2 and R^3 sandwiched between the foil layer F and the insulating support S is shown in Figure 34. This stock can not only give a still wider range of resistance values, but it can also simplify the differential dissolution of the resistance layers. This is done by making the central resistance layer R^2 very different in solubility from the other resistance layers R^1 and R^3. If the layer R^2 were for example lead sulphide and the layers R^1 and R^3 were for example carbon-filled resin films soluble in alcohol, a step-by-step dissolving procedure could be employed using acid and methylated spirit as the only solvents, and using alcohol-soluble and alcohol-insoluble acid-resisting inks or lacquers respectively as the two protective media. The lead sulphide film R^2 would protect the lower resin-bonded film R^3 from the action of an alcohol solvent when the upper resin-bonded film R^1 is being dissolved, while an acid would dissolve the lead sulphide film R^2 without attacking the lower layer of resin-bonded film R^3 or the protective media.

The layer R^2 can be produced electrolytically on the metal foil F which has previously been coated with the carbon-filled resin layer R^1 by first plating a very thin film of lead on the layer R^1 and then chemically converting this lead film into lead sulphide. If required this process can be repeated until a sufficiently thick layer R^2 has been obtained. Alternatively the layer R^2 might be formed by other methods, such as deposition from the vapour state or by chemical mirror formation.

Although the production of the stock has been described with particular reference to starting with the metal foil F, as is the preferred procedure, it will be appreciated that one can start with the insulating support S, and coat this support with one, two or more resistance layers, finally electro plating the outermost layer with copper or with another highly conductive metal to a sufficient thickness, this electro-plated layer constituting the layer F. Alternatively it would be possible to deposit the metal layer on the outer resistance layer by vacuum deposition, this deposit being reinforced if necessary by plating.

By the use of a highly conductive cement, such as one made of a "Markite" conductive plastic material as referred to above, or such as a fine silver powder in a conventional adhesive, the metal foil could be cemented to the outermost resistance layer. Alternatively a conductive plastic could be coated on the outermost resistance layer and then electro-plated or solder-painted to provide the conducting layer. These arrangements also give a strong bond between the conducting layer and the outermost resistance layer.

From the point of view of electrical characteristics the conductive cement can be regarded as part of the foil, and must of course be removed with the foil during the etch treatment or subsequently.

The many possible variations in methods and materials for carrying out the invention permit a selection of those most suitable for each particular application. Printed circuits containing resistors are preferably manufactured from stock in which resistance layers are directly coated on to a metal foil. Conductive cement is preferably used when a resistance layer is formed either directly on an insulating support or independently as a self-supporting film which is stuck on to an insulating support. This method can also be used for the production of separate resistors for attachment to printed circuits, e.g. labels, strips or transfers.

One feature common to most aspects of the present invention is the necessity for printing, stencilling or otherwise treating certain areas of a sheet in correct register. It is of course possible to use any of the usual methods of register printing to achieve the desired result, but the etching step affords a simple means for providing mechanical registering of the second and any subsequent printing or coating steps in relation to the first imprint. This can be done by providing for holes or edges at suitable points in the foil areas during the first printing thereon of a protective coating, so that the foil is etched away at these holes or edges in the etching step which follows this protecive printing. Then by using these holes or edges in the foil, the printing plates or stencils for subsequent printing or coating operations can be brought mechanically into register.

In a previous example the exposed resistance layer is coated with a varnish or lacquer to protect the layer during any subsequent stages of the processing and for permanent protection afterwards (see Figures 31-33). It has been found that the influence of such coatings is not always compatible with the aim of exact predetermination of the resistance value, since the resistance value is often influenced by the coating in an unpredictable way.

In order to avoid this contingency and to provide protection for the exposed areas of a resistance layer these areas may be provided with a protective mesh screen, for instance of a resinous material. This screen can be applied in several ways. In one method the metal foil is coated, for instance by printing with a suitable screen before it is bonded to the resistance layer. The screen can be of any convenient shape, for instance a mesh of crossing lines. In another method, instead of the screen being applied to the surface of the foil, grooves may be etched or otherwise produced in the foil and the screen-forming substance placed in these grooves. Before the resistance layer is coated on the screen-bearing foil, or before the foil and the resistance layer are bonded together with the screen between them, the screen-forming substance should be properly set, e.g. polymerised, so that this substance cannot influence the resistance value in an unpredictable manner. Thus when the metal foil has been etched away the mesh screen will remain superimposed upon the resistance layer.

In the areas where the resistance layer has to be removed, a solvent for the screen substance may be applied first so as to expose the whole of the resistance area which is to be removed. Alternatively, if the resistance layer is to be removed by washing with an agent which attacks the cement by which the resistance layer is secured to the underlying layer, there may be no necessity for first removing the screen, since this will come away with the resistance material.

By making the screen-forming substance slightly conductive, for instance by including a small amount of colloidal graphite or other carbon particles therein, the electrical characteristics of the resistance layer will differ somewhat from those of an equivalent unscreened layer, and some useful additional effects can be achieved. For instance, the screen will bridge any pinhole or fine crack in the resistance layer without significantly altering the electrical characteristics of the screened area. By varying the widths of the lines in the screen different resistance values per square area can be obtained. This can also be done by superimposing two or more screens formed of substances which are capable of selective removal, so that by suitable treatments exposed areas of either screen can be removed. It should be borne in mind when superimposed screens are used that areas of metal foil must remain visible in the interstices between the screens to permit the resistance material to make contact with the foil.

Reference has been made above to the possibility of providing temperature-stable resistance layers consisting of certain metal alloys. Temperature-stable layers of carbon-filled resistance material can be achieved as follows. Such layers normally have a negative temperature coefficient of resistance, but if the layer is mechanically strained the resistance will increase with the strain. Thus by causing the insulating support to expand or otherwise change its shape as the temperature rises, in such a manner as to increase the mechanical strain of the layer, the negative temperature coefficient can be wholly or partly compensated. This principle can be employed also to give, within limits, any desired temperature coefficient, and resistors embodying the principle may

therefore be employed in many forms of apparatus where indication, measurement or control as a function of temperature or strain of the resistance layer is required. If the temperature-strain characteristic given by the expansion of the insulating support is not satisfactory a bimetallic thermometal strip can be secured to the insulating support on the side opposite to the resistance layer in question. This thermometal strip will bend as the temperature changes, thus stretching or compressing the resistance layer depending upon the direction of bend, thus altering the resistance value of the resistance layer. Both carbon and metallic resistance layers can be used with this arrangement, and according to the matching of the various elements either a degree of compensation of the temperature constant of the resistance layer, or an accentuation of it for temperature indicating purposes, can be achieved. It will be appreciated that the influence of strain on the resistance value of a resistance layer can be used for other purposes as well.

Resistance layers consisting of colloidal graphite in an elastic resin such as a silicone or chlorinated rubber, have been found to exhibit in a satisfactory degree the property of varying their resistance in dependence upon strain. An elongation increases the resistance and a compression decreases it. Other resistance layers have the same property.

Thus by mounting such layers on flexible supports in accordance with the invention they can be used as rheostats or variable resistors for a variety of purposes, such as strain gauges, volume controls, pressure gauges, diaphragm microphones or gramophone pick-ups and the like, where the support is deflected in accordance with a change in a variable quantity and the change in the resistance value provides a measure of the change in the variable quantity.

Conveniently, therefore, such a resistor may be incorporated in a device adapted to subject the insulating support to mechanical force and associated with an electric circuit for indicating the resistance value of the resistor and hence the magnitude of other characteristics (e.g. frequency) of the applied force.

What we claim is:—

1. A multi-layer stock for the manufacture of electrical resistors (as hereinbefore defined) or printed circuits containing them, which comprises an insulating support, at least one layer of electrical resistance material adhering to the support, and a layer of a highly conductive material of negligible square area resistance adhering to the resistance material and in intimate electrical contact therewith.

2. A multi-layer stock as claimed in Claim 1 in which the insulating support and the other layers are flexible.

3. A multi-layer stock as claimed in Claim 1 or Claim 2 in which there are at least two layers of resistance material between the insulating support and the highly conductive layer, these resistance layers having such different chemical and/or physical properties as to render them susceptible of selective removal.

4. A multi-layer stock as claimed in Claim 1 or Claim 2 in which there are three layers of resistance material between the insulating support and the highly conductive layer, the centre resistance layer having such different chemical and/or physical properties from those of the other resistance layers as to render the layers susceptible of selective removal.

5. A multi-layer stock as claimed in any one of the preceding claims in which the insulating resistance layer adjacent to the insulating support is bonded thereto by an insulating cement.

6. A multi-layer stock as claimed in any one of the preceding claims in which the resistance layer adjacent to the highly conductive layer is bonded thereto by a conductive cement.

7. A multi-layer stock as claimed in any one of the preceding claims in which the highly conductive layer consists of metal foil.

8. A multi-layer stock as claimed in Claim 7 in which the highly conductive layer and the resistance layer adjacent thereto consist of a bimetal strip or sheet, this resistance layer comprising a thin layer of a metal which has a high specific resistance and which is unattacked by at least one agent which is capable of removing the highly conductive layer.

9. A multi-layer stock as claimed in any one of the preceding claims in which the resistance layer, or at least one of the resistance layers where there are more than one, consists of a "semi-conducting" substance.

10. A multi-layer stock as claimed in any one of the preceding claims in which the resistance layer, or at least one of the resistance layers where there are more than one, consists of carbon particles in a binder.

11. A multi-layer stock as claimed in Claim 10 in which the binder is elastic.

12. A multi-layer stock as claimed in any one of Claims 1 to 8 in which the resistance layer, or at least one of the resistance layers where there are more than one, consists of carbon or graphite of a dense single-phase structure.

13. A multi-layer stock as claimed in any one of the preceding claims in which the resistance layer, or at least one of the resistance layers where there are more than one, is of reticular form and the resistance per square area has different values for different directions of the resistor axis.

14. A multi-layer stock as claimed in any one of the preceding claims in which there is a mesh or screen between the highly conductive layer and the resistance layer adjacent thereto, which will protect the resistance layer at least underneath the lattice of the mesh or screen when an area of the highly conductive layer is removed.

15. A multi-layer stock as claimed in Claim 14 in which the material of the protective mesh or screen is slightly electrically conductive.

16. A multi-layer stock as claimed in Claim 15 in which the highly conductive layer consists of metal foil and the protective mesh or screen lies in grooves formed in the foil.

17. A multi-layer stock as claimed in Claim 14 or Claim 15 or Claim 16 in which there are at least two superimposed protective meshes or screens the chemical and/or physical properties of which render them susceptible of selective removal.

18. A multi-layer stock as claimed in any one of the preceding claims in which the insulating support is readily deformable and the material of the resistance layer, or of at least one of the resistance layers where there are more than one, is such that its resistance value changes when it is subjected to strain due to deformations of the insulating support.

19. A multi-layer stock as claimed in Claim 18 in which the insulating support is either inherently subject to significant dimensional variations in dependence on changes of temperature, or is in operative association with a member which is itself subject to such dimensional variations.

20. A multi-layer stock as claimed in Claim 18 which includes a bimetal strip or the like operative to bend the insulating support in dependence on changes of temperature.

21. A multi-layer stock as claimed in any one of the preceding claims in which the material of the insulating support is very thin and has uniform dielectric properties to make it usable as a capacitor dielectric of known square area permittivity.

22. A multi-layer stock as claimed in any one of the preceding claims in which the insulating support is readily perforable to permit making electrical connections to the inner surface of the adjacent resistance layer.

23. A multi-layer stock as claimed in any one of the preceding claims in which there is on the side of the insulating support opposite to that which carries the said resistance and highly conductive layers, a further highly conductive layer either alone or associated with at least one further resistance layer.

24. A method of making the multi-layer stock claimed in any one of the preceding claims wherein the highly conductive layer consists of metal foil, which comprises applying the resistance layer or layers to the foil by a coating process and then securing the coated foil to the insulating support with the resistance layer or layers between the foil and the support.

25. A method as claimed in Claim 24 which includes heat treating the foil after the resistance layer or layers have been coated thereon.

26. A method of making the multi-layer stock claimed in any one of Claims 1 to 23 which includes the final steps of exposing the resistance layer or layers in selected places, ascertaining the square area resistance value of these layers, and marking the stock to indicate the values thus ascertained.

27. A method of making a resistor, or a printed circuit containing a resistor, from a stock as claimed in any one of Claims 1 to 23 which comprises selectively removing certain areas of a layer or layers by treatment with an agent or agents capable of removing the said layer or layers while protecting from the action of the agent or agents those areas of the said layer or layers that are to be retained.

28. A method as claimed in Claim 27 in which the protection is at least partly afforded by the presence of an overlying layer which is unaffected by the said agent or agents.

29. A method as claimed in Claim 28 wherein the highly conductive layer of the stock consists of metal foil, which comprises first removing metal foil only from areas in which the underlying resistance layer or layers are to be removed, and then removing the unwanted areas of the resistance layer or layers by an abrasive treatment, the other areas being protected from abrasion by the metal foil.

30. A method as claimed in Claim 27 or Claim 28 in which the protection is at least partly afforded by the application of a protective coating prior to the treatment with the said agent or agents.

31. A method as claimed in any one of Claims 27 to 30 in which the highly conductive layer of the stock is metallic and is removed by an etching process from areas where it is not required.

32. A method as claimed in any one of Claims 27 to 31 in which areas of exposed layers which are to be retained are printed over with an ink which resists the action of the removal agent or agents.

33. A method as claimed in any one of Claims 27 to 32 whereby at least two layers of resistance material or at least one layer of resistance material and the support are exposed in different areas, which comprises first applying to the highly conductive layer a protective pattern which leaves unprotected the area of the lowest layer or the

support which is to be exposed, removing from the unprotected area the highly conductive layer and any other layers overlying the said lowest layer or the support, then removing some of the protective pattern to expose the area of the next layer which is to be exposed, and finally removing the highly conductive layer from this now unprotected area.

34. A method as claimed in Claim 33 in which the part of the protective pattern which has to be removed prior to the second stage in the removal of the unwanted parts of the stock is susceptible to removal by an agent which will not affect the rest of the protective pattern.

35. A method as claimed in claim 34 in which the parts of the protective pattern which are capable of selective removal are formed by printing on the highly conductive layer with two different inks, one of which can be removed by an agent which will not affect the other.

36. A method as claimed in any one of Claims 27 to 35 which includes the step of applying a protective coating to the highly conductive layer in such a manner that at least at one place at the boundary of a coated area there is a serrated edge or other progressive diminution in the effectiveness of the protection, thereby providing a relatively gradual transition between a highly conductive area and a resistance area at this place in the resulting product.

37. A method as claimed in any one of Claims 27 to 36 which includes forming holes or edges in the highly conductive layer during the first removal of portions of this layer, which holes or edges serve as registers for a stencil or printing appliance employed in a subsequent operation.

38. A method of making a printed circuit substantially as herein described with reference to Figures 1 to 7, or Figures 9 to 15, or Figures 16 to 24, or Figures 25 to 33 of the accompanying diagrammatic drawings.

39. A resistor or a printed circuit made from a multi-layer stock as claimed in any one of Claims 1 to 23.

40. A resistor or a printed circuit when made by a method as claimed in any one of Claims 27 to 38.

41. A resistor made from a multi-layer stock as claimed in Claim 18 and incorporated in a device adapted to subject the insulating support to mechanical force and associated with an electric circuit for indicating the resistance value of the resistor and hence the magnitude or other characteristic of the applied force.

KILBURN & STRODE,
Agents for the Applicants.

PROVISIONAL SPECIFICATION

Improvements relating to Electrical Resistors and Printed Circuits.

We, HAROLD VEZEY STRONG and PAUL EISLER of 32, Shaftesbury Avenue, London, W.1, both British subjects, do hereby declare the nature of this invention to be as follows:—

The present invention relates to the manufacture of electrical resistances, particularly of flat resistors consisting of resistance layers on stiff or flexible insulating bases and of resistances in so-called printed circuits required either in the form of lozenges, labels, strips, or transfers (delcalcomanias) for insertion into circuits or as an integral part of the printed circuit avoiding any connecting operation between the resistance and the metal pattern of the circuit. The last form is the more complicated and will be described fully; the production of single resistances or resistance groups for insertion into circuits is only a special case of the fully described method for production of the resistances as integral part of the printed circuit. With lozenge resistors and the like, the metal pattern is a particularly simple one. It consists of the terminals only and consequently a number of modifications, simplifications and omissions of steps are possible in this case which need not be gone into here as they will be self-evident to those skilled in the art, once the idea of the present invention has been fully understood.

The invention proposes in its main species the production of a multi-layer sheet material, stiff or flexible, consisting at least of one highly conductive metal layer, preferably a metal foil or an electro-deposited metal film on one side of the sheet, of an active resistance material in intimate contact with the above metal layer in the centre, and of an insulating base on the other side, all three layers firmly bonded together. Instead of one layer of active resistance material, two or more such layers of different specific resistance value per square area and different composition, may be used without any insulating layer separating them from the metal foil, or the resistance material layers from each other. It is permissible, however, to use an insulating cement between the insulating base and the film of resistance material.

This multi-layer sheet material is the stock or raw material so to speak for the production of the resistances at any desired place of a metallic pattern which at the same time forms the terminals of the resistors as well.

The process consists essentially of printing a pattern on the metal layer of this stock, for instance in an acid resisting ink, dissolving the metal and all the resistance film or films, on the non-protected areas, then again by printing or marking or differently dissolving the original two colour print to expose the metal layers over the resistance areas only to the acid which will leave the (first) resistance layer unattacked. In the case of a double resistance layer the process continues by affording new protection to the first layer on those places of the pattern where it ought to remain and remove it on others by a solvent which does not attack the underlying second resistance layer. This method of differential dissolution as applied by the present invention has, of course, many variations some of which will be dealt with later.

The " active " resistance material used by the invention is a thin coherent film or pattern which is coated by any suitable coating process onto a carrier or laminated to same and one of the chief qualities of this material of importance to the method of the present invention is that it is either soluble or fusible, and is " conductive " not only on one surface but across the thickness as well.

The following are examples of this resistance material: A thin continuous metal film or a continuous layer of a " semi-conducting " metallic oxide or other metal-compound produced by vacuum deposition or a very thin electro-deposited metal or chemically produced metal or metal - compound " mirror " such as a lead sulphide film, a film of a metallic colloid or fine metallic powders in a " binder " and, most important of all, a film of carbon powders or graphite powders or colloidal graphite in a binder. While the films of thin metal or metal-compound require deposition onto the carrier in vacuum or in a bath the films containing the conducting particles in a binder can be produced by coating, for instance roller coating, the carrier with a solution or emulsion of the material the volatile agent being driven off, or evaporates subsequently, or by coating it e.g. in a hot melt machine with the material at a temperature at which the binder is liquid. It is further possible to form films from about half a thousandth of an inch up to a few thousandths of an inch by the known methods of making plastic films which are self supporting without a carrier and laminate these films to the carrier, for instance by heat and pressure or, in the case of an insulating carrier, by the use of an insulating adhesive, and in case of a metal foil carrier by a conductive adhesive.

The "active" resistance material need not necessarily consist of an all over coating or film. It can be a pattern consisting of a network of lines straight or curved, thin or thick, wide or narrow. In a special case it may consist of incoherent parallel lines or even dots on the surface of a coherent resistance film which is adjacent to the conductive metal foil. As to the production of very uniform coatings and patterns of resistance material our application No. 7,299 (Serial No. 690,696) dated 17th March 1949 is referred to.

The binder is a glue, rubber or resin—synthetic or natural—or rather a resin mixture plasticised if required to render it non-brittle, strongly adhesive and compatible with the conductive particles, usually carbon, it is filled with. The binder must have no water absorption or be capable of being rendered water insoluble and non-absorbent, it must be resistant to the process of dissolving or depositing metals and not influenced by the chemicals used in this process, that is it must be resistant and uninfluenced by acids or electrolytes in the concentrations used in the metal patterning processes employed. Of particular importance is the resistance to iron perchloride or the copper sulphate bath as these chemicals are the most frequently used for copper pattern production.

As it is desired to use a flexible carrier for preference and to make the resistances suitable for flexible circuits as well, the binder should be very flexible.

The higher the temperature stability of the binder and the stronger a bonding medium it is between metal (copper foil) and the insulating base of the printed circuit the better.

A further requirement for the binder is its solubility or heat fusibility at a lower temperature than the softening point of the insulating base. Preferably it ought to be soluble in a solvent other than water or the acid or electrolytes used in the metal patterning process to which it must be resistant. For those applications where a double coat or a two layer laminate of two resistance materials of different specific resistance value is used the binder of each material must be soluble in a solvent but remain unattacked by the solvent of the other binder. The second binder generally need not, in this case, be as resistant to the chemicals used in the metal patterning process as the first binder.

The following are examples of suitable binders:

Bichromated fishglue made water and acid proof by heating to about 350°C. (made up with colloidal graphite or carbon-powder in water to give a resistance film when coated onto copper foil).

Acetic acid soluble resins such as Ethyl Cellulose.

Sodium or ammonium alginate or Sodium carboxy methyl cellulose films made insoluble by acids and remaining soluble in

alkalis (not favoured).

Resins such as Shellac or Vinyl Acetate being soluble in alcohols but not soluble in aromatic hydrocarbons.

Synthetic rubbers e.g. Neoprene or resins such as styrenes being soluble in aromatic hydrocarbons but not attacked by alcohol

Cellulose Acetate or Nitrate, or Polyiso butylene based adhesive mixtures can be used with Acetone as solvent; Silicone rubbers and non-thermosetting adhesive resins Polyvinyl chloride, etc., make quite suitable soluble binders of relatively high temperature stability while modified waxes, polythene, etc., are examples of fusible binders applicable only for very low wattage loading of the square area.

Although the above list is by far not exhaustive it can be seen that quite a number of substances can be selected as binders which comply with the requirements outlined above more or less fully and quite a number of binder combinations are possible which would permit of the differential dissolving of films formed with them.

As seen from the above list as well, there is a wide range of active resistance materials which can be selected. The principles guiding this selection are manifold; some are quite obvious such as the necessity to use a more flexible material when the insulating base and/or the carrier is itself flexible or be bent over a smaller radius than is required when the material is on a stiff base or carrier.

Another obvious selection point is the specific value of the square area resistance required for the particular resistor. The materials consisting of carbon in a binder or lead sulphide films or films containing so called semi-conducting substances are generally more suitable for high ohmic resistances than films made by vacuum—or electrodeposition of a metal either pure or alloy.

The wattage loading per square area of a silicone bound carbon film carried on a silicone impregnated fibre cloth base will be very much higher than the loading permissible with a shellac film on an impregnated paper base and consequently the resistors can be made very much smaller with the former materials than with the latter.

As the binder has often also to act as a cement between the conductive metal pattern made of copper foil for instance, and the insulating base, it must be suitable as a cement to bond these two materials, or it must bond to the coated metal foil and the insulating base or be easily cemented by an ordinary adhesive to the insulating base.

The application where the noise level matters, the formation of the conductive particles in the film is a selection principle or an indication to use a metal or metal-compound film.

In a design using two overall coats of resistance material the resistance of the second coating to the chemical used for the metal patterning process is less important than that of the first coating, while its resistance to the solvent of the first coating must be very marked. This is a further guiding point in selection of the most suitable combination of materials, and explanation of the wide variety of materials desired to enable the best choice to be made for each application.

Having now given an account of the type of resistance materials used by the invention, the method of resistance manufacture will be described in the following mainly by way of examples.

For this purpose it is advantageous to make reference to some specific procedures, solvents or other substances which are used in conjunction with the materials selected for the examples. They would be modified or replaced by others in case other materials were selected for other specifications of resistances to be produced according to the invention and thus in no way restrict the scope of the invention to the examples described.

The first example will be the production of a circuit containing only resistances of such value that all can be obtained from one layer of resistance material using only the aspect ratio and the terminal position and terminal width to achieve the different values required.

Our raw material may be made up as follows: A copper foil is roller coated with a mixture of colloidal graphite or carbon in water and bichromated fishglue which is dried in light and then heated to about 350°C. so that the glue film is "burnt" into the copper foil and has become insoluble in and unattacked by water and acid such as iron perchloride. It is firmly adherent to the foil on which it forms a conductive coat of great flexibility if the right type of glue was used. For still greater flexibility various plasticisers are available which are mixed with the glue prior to coating.

The coated side of the foil is now cemented to an insulating base, say to an insulating paper using a synthetic rubber type cement soluble in acetone. We have now a flexible multi-layer sheet: a copper foil-insulating paper laminate with an interleaving layer of a carbon-filled glue film in direct contact and firmly adherent to the copper foil. A roll of this laminate is calibrated by cutting out test pieces at various selected points of the length and width of the laminate and printing and patterning the test pieces to a standard design, but employing the same and all the methods and means and timing as are used for the circuit manufacture which will be described presently. If the resistances of the test pieces are found to be of suitable performance, their value to be sufficiently uniform and originating from a sufficiently

uniform square-area resistance, the roll is marked with the value of this square area resistance and this value is the basis of the design of the pattern of the circuit as much as the datas of the copper foil or insulating base.

The pattern consists of the areas of the metal conductors of the circuit including connection areas, areas which form capacitors, shielding, terminals, interconnections, etc., and areas of different length to width ratio which ought to give the resistors required in the circuit. From our point of view the pattern divides the multi-layer sheet into three distinct areas, namely:

(A) One from which both the metal foil and the resistance layer is to be removed, leaving the insulating base without any conductive coat.

(B) One from which the metal foil only is to be removed leaving on the insulating base the resistance film.

(C) One from which nothing is to be removed leaving there the metal foil and the resistance film over the insulating base.

The pattern is printed on the metal foil. A number of printing procedures are possible and some will be described for the sake of giving examples. The first may be called a two-colour printing, the word "colour" being used in analogy to the normal printing procedure, when two different inks are used to distinguish two areas visually. Here we are, of course, not so much interested in visual distinction except for process control reasons as for the differences in the inks used. We print the areas C of the metal foil with an ink *c* and the area B with an ink *b*. Or ink b may be printed on areas B and C, except those parts of area C which finally ought to show the copper foil blank (terminal and connection areas) and ink *c* be over printed on ink *b* on all the areas C, but C only. Both inks *b* and *c* are acid and alkali resisting inks but have different solvents, such as aromatic hydrocarbons for one ink and aliphatic hydrocarbons for the other. Ink *c* can be acid resistant only and attacked by alkalis.

Having made this two colour print we submit the sheet to a metal dissolving process for instance a chemical etch bath such as an iron perchloride bath, until all the metal in areas A is completely removed and then to an alkali which will remove the resistance film (fishglue) on the areas A. This removal is helped if the cement used to bond the fishglue coated foil to the insulating base is not alkali resistant either.

Alternatively, if the cement and ink *b* have the same solvent, say alcohol, a mixture of methylated spirit and caustic soda may be used instead of the pure alkali or the sheet may be treated with alkalis and alcohols successively and repeatedly to make sure of complete removal of the resistance film on areas A.

If ink *b* is still over areas B the next step is its removal from there by treating the sheet with the solvent of ink *b*. The metal foil on areas B and the ink *c* and the metal foil on areas C act as resist to protect the resistance film and cement underneath the metal foil from all the solvents or alkalis used so far. But we now have the areas A free of metal and resistance film or even cement, an inked metal foil over areas C and a bare metal foil over areas B.

We are now treating the sheet again with the acid etch, say iron perchloride, which removes the metal foil over areas B but leaves the resistance film (fishglue) unattacked and after washing with water remove ink *c* with its solvent, say benzene.

If we have printed as in the first variety (no overprinting of inks *b* and *c*) we have now a blank metal foil pattern. If we have printed as in the second variety (ink *c* over ink *b* as described) we have a metal pattern which is covered with ink *b* except on the terminal and connection areas of C where the metal is blank. During the process ink *c* has protected ink *b* on the overprinted areas from the influence of the solvent of *b* or the alkali. In all cases the metal pattern rests on top of a resistance film which is in most intimate contact with it—in this case it is coated on and burnt into the metal foil—and thus the problem of providing terminals by metallising the ends of a resistance film is eliminated. Furthermore, foil terminals are provided which are shaped by a printing process so that the best form for these terminals can be arranged very conveniently. They may have instead of the usual straight line border between terminal and resistance film, a serrated one with many thin tongues of metal protruding into the resistance area, resistance film extending between the tongues. It is also possible and preferred to have the foil thinned down towards the resistance area by using a similar technique in printing and etching as is used for getting different tone values in making a gravure cylinder. This technique consists essentially in making the ink over the areas of the resistance terminal gradually less resisting to the acid the nearer one gets to the resistance area. That can be done by using a continuous tone printing technique, such as gravure, relying on the variation of ink thickness to give the variation in acid resistance required, by using a third ink on the areas in question relying on the same effect, or by a kind of half-tone of the pattern of ink *c* overprinting it over ink *b* so finely that, when ink *b* is dissolved, neither the ink *b* underneath the half-tone pattern of *c* nor the metal foil in this area is removed completely during the time of the treatment in solvent and acid the

degree of dissolution being among others a function of the density of the half-tone. If the printing is done photographically the ordinary photogravure method is applicable: the varying degree of light hardening of the gelatine determines the permeability of this resist to the iron perchloride and thus the degree of etching of the copper foil. The ease with which it is possible to provide a terminal upon and in most intimate contact with the resistance films consisting of metal foil (or deposited metal as shown later) which may have a fork and wedge shape or both is a particular achievement of the present invention.

A variation of the printing and etching procedure makes it unnecessary to use several inks of different solvent characteristics and enables the removal of the coatings (resistance film, cement) of area A to be done more drastically, for instance by assisting the chemical dissolution with swabbing or gentle scratching. The scheme is the following:

First a print with acid resisting ink is made on area B and C without distinction between B and C, and the sheet is etched so that the metal over area A is completely removed. The solvent of the ink and of the cement bonding the resistance layer to the insulating base may be the same. This solvent, with or without alkali, is now used preferably with assistance of a mechanical swabbing action to remove all the resistance film and cement from areas A as well as the ink from areas B and C. The sheet is now coated all over by printing, painting or spraying with an ink, lacquer or other resist, except on areas B which at this stage are kept masked by a stencil or kept protected from being coated by the use of a suitable printing plate or printing procedure. Consequently the foil on areas B remains blank. The metal is now removed from the areas B by etching again. If desired the ink or lacquer on all areas A and C may be dissolved and a new lacquer coating applied all over the sheet leaving bare the metal terminals and connection points of area C.

The result of the procedure in any of the variations described is a printed circuit with a metal foil pattern and integral resistors of any value which can be derived from a single resistance coating. In very many cases this range of values will not be sufficient and two or even more materials of different square area resistance value are needed to enable all the various resistors or most of them to be obtained. The present invention provides for this requirement by creating two or more layers of such materials on the same carrier, ono layer on top of the other. The raw material for the circuit production accordingly consists in this case of a metal foil and an insulating base sandwiching two (or more) resistance layers in intimate conductive contact with the metal foil. Taking two layers as sufficient for the circuits in question the two films must not only have the required square area resistance values r_1 and r_2 but also two solvents s_1 and s_2, so that layer r_2 is not attacked by solvent s_1 and layer r_1 (or an ink or lacquer or other film which can be coated over r_1 at a certain stage of the patterning process) must not be attacked by solvent s_2.

As outlined earlier on in this application there are quite a number of resistance materials which can be selected to form such double layer resistance coats. Burnt-in carbon filled fish glue, with any of the synthetic resin bound carbon films, will give a workable combination and so will metal or metal compound films with films using an organic binder. Any fairly different pair of materials will be worth considering subject to the other requirements mentioned. Recently a series of thermo-setting, thermo-plastic and elastomeric variants of new conductive materials, called Markite conductive plastics, have been brought out with a conductivity range from that approaching the resistivity of mercury to that of high-conductivity rubber, Boron and above. (See "Electronics." October 1949, page 96 to 99 inclusive. "Electronics" is a McGraw Hill publication, McGraw Hill Publishing Company Inc., 330 West 42nd Street, New York, U.S.A. London office: Aldwych House, Aldwych, London, W.C.2.) Thin films or coatings (lacquers, varnishes or cements) of two differentially soluble Markite plastics or of a Markite plastic material and another resistance layer of the previously mentioned type are, of course, also possible combinations for our purpose.

Digressing for a moment from the example under review it is worth noting that the range of Markite Plastics as published in the above reference offers a remarkable selection for single as well as multiple resistance layers.

When the present supply situation alters these materials might become the preferred materials for making the active resistance layers of the invention. They are to be treated, when used as resistance layers, in the same way as the carbon filled resin films, described extensively in this application.

Furthermore, highly conductive adhesives could be developed from Markite plastics which could be used to cement or laminate or—as it is claimed in the reference given above, even solder—a thin self-supporting film of resistance material or a resistance layer produced on an insulating base by coating the insulating base to a metal foil provided always that this adhesive has a solvent which does not affect the resistance layer or that it can be fused off, that is removed by

heat or by a heated tool like the fusible metal of our application No. 10023 of the 15th April 1947 (Serial No. 639,658), from the resistance layer at a temperature not affecting the latter.

For our purpose such a highly conductive adhesive layer is to be considered as if it was a part of the metal foil. It serves only to give a conductive bond between metal foil and resistance layer enabling the use of resistance films not produced on the foil itself. Whenever and wherever the metal foil is to be removed from any area the conductive cement must be removed as well. Regarding the use of the conductive plastic for metallising the resistance layer by other means than a foil and as a printing ink see later.

For the two examples to be described using superimposed resistance layers in intimate conductive contact with each other and the foil, we select a thin lead—or lead compound film and a carbon filled neoprene as one pair of resistance films and a carbon filled shellac—and carbon filled polyvinyl chloride film as the other combination.

In the first case the copper foil is first electro-plated with an extremely thin lead film and then roller coated with a carbon filled neoprene solution. (In case of a metal compound being wanted as resistance film the thin metal plating is chemically transformed wholly or partly into the compound after plating; for instance into the metal sulphide by treating the plated side of the foil with a solution of sodium sulphide. A film of lead sulphide may be obtained in this way for example, and constitutes a suitable resistance layer.) A pure (insulating) neoprene cement is coated on the insulating base and the double coated foil and the cement coated insulating base are laminated together. The test procedure for ascertaining the resistance values achieved is, in principle, the same as described previously.

The raw material for the second example is made by first coating a carbon filled shellac solution all over the copper foil, for instance by means of a capillary coating device as described in our application No. 7299 of the 17th March 1949 (Serial No. 690,696), and then by ruling onto this coating a network of lines with a carbon filled polyvinyl ink and again cementing the foil to an insulating base.

The shellac and the P.V.C. solutions are both heavily dyed in contrasting colours to make a visible distinction of both coatings. The network of lines shows a very fine repeat with very frequent crossings of lines but it is in this case designed to result in the square area resistance being different for different directions of measurement, thus permitting different values to be obtained for any resistor made from this material, not only by variation of the aspect ratio or terminal length and position on the resistor ends, but also by the direction of the resistor length relative to this network of lines. These values are additional design data important for the design of any pattern out of the material and are empirically determined by the measurements on test circuits produced from the material in exactly the same way as the normal circuits.

Reverting for a moment to the network of resistance lines forming a close intersecting repeat pattern it has been mentioned that the pattern can be made by ruling. Ruling machines, both of the disc- or pen-type which draw parallel straight lines longitudinally and across the foil, may be used, the spacing of the lines in each direction being different if a different value of resistance is desired for different angular position of any resistor made out of the sheet. The pens may be the ordinary ruling pens or ball pens using the offset capillary coating method (see our application No. 7299/49) (Serial No. 690,696). Straight lines, however, are not the only ones possible. The pens may oscillate or be moved in circles or be guided otherwise so that wavy, cycloidal or other curved lines are drawn, or the pattern may be printed with any design of intersecting lines. The ruling of the groups of straight parallel lines at right angle or any angle to each other usually requires two steps, the other methods mentioned require in principle only one step.

Describing the procedure to produce the printed circuit with integral resistors out of the multi-layer sheet prepared, we conveniently again denominate the areas from which finally all metal and resistance film—and, if desired, the insulating cement layer as well—has to be removed as A, the areas of the pattern where metal foil (and solder and conductive adhesive if any would have been used) remains on top of the resistance layers to form the highly conductive part of the circuit as C and the resistance areas as B_1 and B_2. B_1 are areas of resistors of lower value of the square area resistance and are covered by both resistance films, B_2 are resistor areas of higher value of the square area resistance and are covered by the second resistance film only. In case one or both resistance materials are coated, not uniformly all over the foil, but in a directional pattern, the value of all resistors depends not only on the size, aspect ratio, terminal length and position, but also on the resistor direction, that is the angle of the resistor axis to the foil axis. That goes in our example for B_1 and B_2, but of course, the directional variation of B_1 resistors is very slight, while B_2 resistors are influenced by the full degree of directional difference of the pattern.

The raw material of the first example is, as already mentioned, a multi-layer sheet wherein a lead- and carbon-filled neoprene film is sandwiched between a copperfoil and insulating base, the two resistance films (lead and "conductive" neoprene) being in intimate conductive contact with the copperfoil. (No conductive cement was used: the lead was produced on the metal foil directly.)

The design covering areas B_1, B_2 and C are first printed on the copperfoil. We restrict ourselves here to describe one printing, etching and dissolving sequence: others will be easily devised when the idea of the invention is fully understood, for instance a multicolour (three colour) printing—an elaboration of the two-colour printing method used previously.

In our present example we use again a printing in two colours, namely a printing using two inks with different solvents, one overprinted over the other. For the first example we select a bituminous ink which is printed over all areas B and C. The foil is then overprinted with a shellac ink which covers all areas B_1 and C. Consequently areas C are covered by both inks, the bituminous underneath the shellac in, areas B_1 by the shellac ink and areas B_2 by the bituminous ink only.

After printing the sheet is etched either chemically, for instance in a nitric acid solution, or electrolytically by being made the anode in a suitable copper and lead sulphide dissolving bath until all metal (copper and lead) or metal compound (lead sulphide) on the areas A is completely removed. The acid or electrolyte is chosen so that both metals or the foil and metal compound is soluble in the bath. The etching uncovers the neoprene film which is now removed for instance by benzene. This solvent will also remove the cement on areas A and the bituminous ink on areas B_2. The areas C and B_1 remaining inked as the shellac ink is not attacked by benzene. Next the sheet is etched again as before in the acid or electrolytic bath with the effect that the metal (copper and lead) and metal compound (lead sulphide) is removed from areas B_2 leaving the carbon filled neoprene film on these areas unattacked.

Next the sheet is treated with methylated spirit in order to remove the shellac ink from areas B_1. The shellac on areas C is incidentally removed as well but areas C remain covered by the bituminous ink which is not attacked by alcohol and so far was protected from the benzene used previously by the shellac printed over it. The areas B_1 however, are now showing the copper foil bare and the task of the next step is to remove the copper without attacking the lead or lead sulphide underneath and, of course, without attacking the neoprene film on areas B_2. This task is achieved by etching (stripping) the copper anodically in an electrolyte which does not enable the lead or lead sulphide to go into solution. In case of a film of lead lying underneath the copper the electrolyte can be the usual acid copper bath consisting essentially of copper-sulphate and sulphuric acid in a weak solution. Lead sulphide, however, would be attacked by an acid and a neutral solution of copper sulphate kept neutral by the addition of calcium carbonate or any other electrolyte suitable for copper dissolution but not attacking the lead sulphide must be used. It is possible also to start the copper removal in a very efficient quick acid or cyanide bath until only a thin copper film is left, and transfer the sheet then for final copper removal to the slower bath which has no effect on the lead sulphide. Thorough washing is, of course, required after nearly all steps of the process which is now virtually completed. Usually a protective lacquer for instance a nitrocellulose lacquer, or other coating, is finally sprayed or otherwise applied over the whole sheet except on some areas of C which are desired to show a bare copperfoil. Such areas are contact areas, connection points, etc. During the spraying of the nitrocellulose lacquer these areas of C are masked by a stencil and, consequently, when the sheet is treated again with benzene—a non-solvent of nitrocellulose but a solvent of the bituminous ink still covering the areas—the copper foil is cleaned from the bituminous ink on these spots.

The second example differs from the first only by the use of different resistance films. The fact that one of those is not an overall coating but a pattern is influencing the design of the printed circuit pattern, not the processing steps as such, which however are conditioned by the different solvents required for these resistance materials. The same sort of printing method as was used in the first example—with different inks—could be used again, but in order to avoid the use of too many sharply distinct solvents and for the sake of using this example to show more varieties in the way the present invention can be carried out, another printing and dissolving sequence is preferred and described which is analogous to one described previously for a sheet with a single resistance layer.

First an acid resisting ink or an ink resisting to the anodic treatment of the copperfoil in an electrolyte, for instance the copper cyomide bath, is printed on all areas B_1, B_2 and C and the copper foil is removed on areas A by chemical or electrolytic etching completely. A bituminous ink will be suitable for either etching method. Then both resistance films and the cement on areas A are removed by treatment with a common

solvent such as cyclohexanone, which also removes the ink from the copperfoil on areas B_1, B_2 and C. Swabbing may be used to assist the dissolution.

The sheet is now coated with a shellac lacquer all over except on areas B_1 and B_2 where the copperfoil is left blank. This blank foil is subsequently removed by chemical or electrolytic etching and a nitrocellulose lacquer applied all over the sheet except on areas B_2 and those areas of C (contact and connection points) which are desired to remain permanently blank. Then the sheet is treated with methylated spirit which dissolves the shellac lacquer where it is not covered by the nitrocellulose lacquer and the carbon filled shellac binder of the first resistance layer on areas B_2. If desired areas B_2 may finally be coated with a protective lacquer, for instance a nitrocellulose lacquer, by stencilling.

By suitable variation of this "step by step" procedure, solvents may be used which dissolve two or more layers simultaneously, for instance methylated spirit added to iron perchloride would attack the copper and the shellac binder of the first resistance layer.

A sheet with three resistance layers sandwiched between the copper foil and insulating base can not only give a still wider range of resistor values, but also ease the differential solution of the layers if the central resistance layer is very different in solubility from the two others which can be of very similar or identical solubility character. A lead sulphide film, for instance, as central layer between two shellac bound carbon films would enable a step by step procedure using acid and methylated spirit as only solvents and an alcohol soluble and a non-alcohol soluble acid resisting ink or lacquer as masking medium. The metal compound film would protect the second shellac bonded film from the alcohol when the first shellac binder is dissolved, the acid dissolving the metal compound without attacking the shellac binder or masking medium. The central layer can be produced electrolytically on a carbon coated foil similarly as on the foil itself by first plating a very thin layer of metal on the carbon coated foil and transforming this metal chemically into the metal compound, and, if required, repeating the process until a sufficiently thick layer results. It may be formed by other method as well such as vaporisation, chemical mirror formation, etc.

The production of the multilayer sheet starting with a foil is the preferred method. However, it is possible to start with the insulating base, coat this base with one, two or more resistance layers of the same type as described and finally electroplate these resistance layers with copper or with another highly conductive metal arriving at a theoretically similar raw material featuring an electroplated high conductivity metal layer instead of the metal foil. Or one could vacuum deposit the high conductive metal layer on top of the resistance film or films and reinforce it, if desired, by plating. The printing, etching and differential dissolving procedure described would not be altered substantially for these types of raw material but they are inferior to the preferred foil type. By the use of a highly conductive cement such as made of Markite conductive plastic material, or of very fine silver powder in a conventional adhesive an improved multilayer sheet material could be obtained although its production does not start—as is preferred—by coating a foil with resistance layers or by cementing a foil—by means of a conductive cement—to a self-supporting resistance layer or to resistance layer or layers coated on an insulating base. That improvement arises through coating a conductive plastic on to the resistance layer produced on an insulating base and then electroplating, or solder painting, this conducting plastic layer. This should give a stronger bond between the high conductivity pattern C and the resistance layer than would be achieved by straightforward metallising the resistance coated insulating base by any of the usual methods of metallising non metals.

If and when a good conductive printing ink can be obtained or one made, for instance out of the new conductive plastics, the first step of the process of the invention (etching the metal off areas A) can sometimes be saved as the pattern C can then be printed directly on to the resistance coated insulating base consolidated, and the differential removal scheme of the invention only worked for the resistance layers on areas A_1 and B_2.

In this case only a part of the raw material provided by the invention is used, namely a multilayer sheet consisting of two or more differentially removable resistance layers on an insulating base. Areas B may be printed with the same conductive ink which is then removed as was the foil in the last example and areas C and B_1 may be masked with an insulating coating for the differential removal of the resistance layers which is the same procedure as outlined in the examples. The printing with the conductive ink may be done not directly on the resistance layer, but on a temporary support and transferred to the resistance layer like an ordinary paint transfer.

The many possible varieties of the carrying out of the invention permit of a selection of the most suitable variety for each class of application. Printed circuits containing resistors are preferably done from foil laminates with a directly resistance-

coated foil. Conductive cement is preferably used when the resistance layer has to be produced on an insulating base first, or only such material or only extruded or otherwise formed self-supporting resistance films are available. It is also a good alternative for the production of lozenge resistors (labels, strips, delcalcomanias). In such cases, for instance the other metallisation methods—as distinct from metal foil—may be used notwithstanding the general preference for the foil variety. If and when the promised and claimed improvements in conductive cements and conductive printing inks become commercially available the preferred field of these other metallisation methods will be widened.

One feature common to most variations of the method of the present invention is the necessity to print, stencil or otherwise treat the sheet or a part of same in register. It is, of course, possible to use any of the usual methods of register printing to achieve the desired result, but it is preferred to utilise the etching step to make possible a mechanical registering of the second and any following printing steps in relation to the first imprint. This is done by providing holes or edges in the pattern areas C which are printed as the first step at suitable points of the pattern so that the foil is etched away at these holes or edges in the etching step which follows the first printing and then use these holes in the foil to register mechanically the printing plates or stencils for the printing or coating operations which follow later. The "step by step" procedure described previously is very suitable when this mechanical registering is employed.

The whole description of the invention has, so far, referred to the layers which are sandwiched between the metal foil and insulating base as resistance-layers or -films and it has been mentioned repeatedly that these layers may consist of metal compounds. The example of a lead sulphide was given for use as an ordinary electrical resistance but it is desired to emphasise here two points:

(*a*) A great variety of such compounds can be formed and reference is made to the article of E. Mehl, Ph.D. "Separating Film" and the list of references given in this article which appeared in Vol 74, No. 14, pages 268 and 269 of "Metal Industry" of the 8th April, 1949 (published by The Louis Cassier Co., Ltd., Dorset House, Stamford Street, London, S.E.1). The metal compounds mentioned there (oxides, sulphides, chromates, iodides, selenides, etc.) are used for a different purpose to that of the present invention and the method given there for producing such compound on the metal surface (the foil surface in our case) is not the only one—vaporisation for example being another. The article however illustrates the great variety of films usable by the invention not as separating films but as resistance layers using "resistance" in the sense outlined below.

(*b*) Some of these metal compounds are not only, or not so much, the basis of ordinary electrical "ohmic" resistors but of a number of devices using the semiconductivity and or other special properties of these compounds when they are placed between suitable electrodes and sometimes protected from outside influences, for instance by a lacquer-coating as described in our examples. The distance and shapes of the electrodes, the circuit connections, voltage, current, temperature, conditions, etc., required by these compound films for their functioning as rectifiers and diodes, transistors, light sensitive cells, thermistors, etc., are no concern of the present invention. For the purpose of the invention they are "resistance" films but it is understood that the scope of the invention is not restricted to the production of flat ohmic electrical resistors, separately or integral with a "printed circuit" but extends equally to any electrical component which essentially consists of, or can be made of, one or more patterned or unpatterned films of appreciable ohmic resistance between electrodes. Whether the films are thin metals, semiconductors, or consist of conducting particles within an insulating binder, or whether the ohmic voltage drop, the photoelectric effect, or the rectifying character, etc., of these films is utilised is not a restriction of the scope of the present invention which has called all these films "resistance films" because they all have a higher square area ohmic resistance than the metal layers from which the conductive pattern or electrodes are formed. The principle of the invention is applicable to all the uses and specifications of these "resistance" films alike. The description and explanation of the idea of the invention on the examples of ohmic resistors has been chosen for the sake of clarity and simplicity, but it is understood that the invention is not restricted to the examples given but that its scope covers all electrical components of a build-up similar to the flat ohmic resistors described, even if they are commonly not referred to as "resistances."

It should be also pointed out that the "insulating base" referred to may be used as the dielectric of a capacitor or capacitors of the printed circuit—usually on areas denominated C in the examples given—but sometimes also on areas B. In such cases multilayer sheets may be used which have the dielectric insulating base sandwiched between two resistance coated metal foils, or between any variety of the multilayer sheets described. The other face of the dielectric

base may be metallised only without a resistance layer between the high conductivity surface layer and the dielectric. Alternatively the capacitors may be formed by folding or superposing the multilayer sheets which have the insulating base as one of the top layers as in the examples given. The procedure according to the invention is not altered for the case of a multilayer sheet with the insulating base in the centre of the sandwich and metal on both covers, except insofar as what has been described for one side must be applied to the other side of the insulating base as well.

Finally, it should be mentioned that the dielectric insulating base may be coated as a thin film onto the resistance coated metal foil as described in our applications No. 27195 (Serial No. 690,328) of the 20th October 1948 and No. 29350 of the 11th November 1948, or coated to one metal foil previously resistance coated or not and laminated to another such foil, or two such coated foils be laminated together to form the multilayer sheet material with metal foil on both faces and a dielectric film in the centre while resistance layers are sandwiched between the metal foil and the dielectric film, the resistance layers being in intimate conductive contact with the metal foil.

Dated the 28th day of October, 1949.

PAUL EISLER

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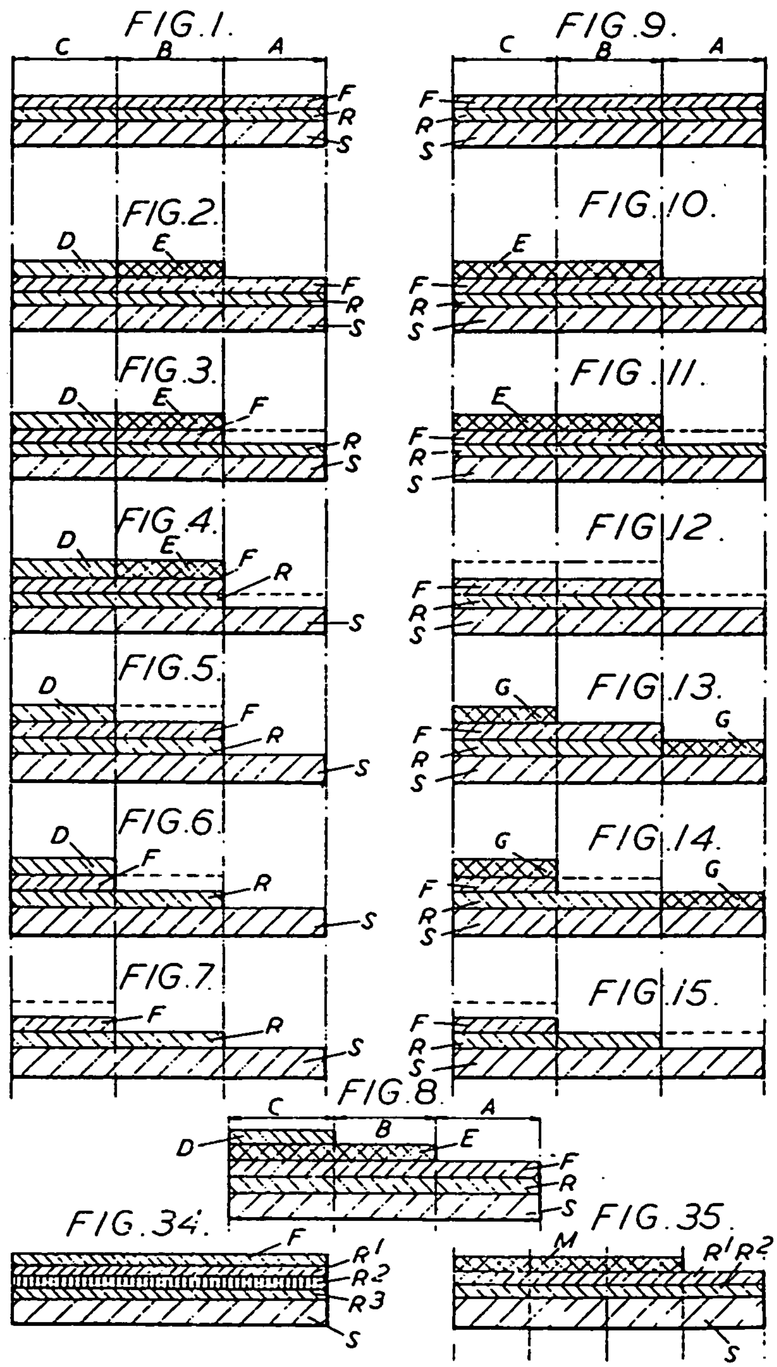

FIG.1. FIG.9. FIG.2. FIG.10. FIG.3. FIG.11. FIG.4. FIG.12. FIG.5. FIG.13. FIG.6. FIG.14. FIG.7. FIG.15. FIG.8. FIG.34. FIG.35.

690,691 COMPLETE SPECIFICATION
2 SHEETS
This drawing is a reproduction of the Original on a reduced scale.
SHEETS 1 & 2